A Novel Approach to Fit Analysis of Virtual Fashion Clothing

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Abstract

A number of 3D design systems are available on the market for use in the fashion industry. They support simulation of 2D pattern pieces on an adjustable virtual mannequin to visualise the 3D appearance of fashion clothing. This offers an opportunity to check fit and pattern flaws in the virtual state so that the initial 2D pattern pieces might be refined. This enables faster detection of any error and earlier correction of design elements, material selection and assembly technique to reduce the dependency on physical prototyping and to shorten the development lead-time and the associated costs. At the same time, virtual prototypes can be used as a marketing aid for online product presentation and Internet-based retailing. However, published literature reveals that only visual presentation and analysis of drape simulation is solely not enough to ensure the meaningful use of such tools in the fashion-product-development process, especially in the situation of decision- making on accepting or rejecting a virtual prototype, or altering pattern pieces to achieve the desired fit.

This paper discusses an objective approach to virtual fit analysis by identifying and analysing three technical parameters of virtual drape, namely tension (gf/cm), stretch (%) and pressure (dyne/cm^2 or gm/cm^2), that work on virtual clothing. Digital pattern pieces of ladies' blouse with varying eases were drafted using a clothing CAD system; a female avatar was appropriately adjusted using the extracted average measurements from a set of body-scan data before simulating virtual blouse on to it. For use in virtual simulation, the physical and mechanical properties of a selected woven fabric were tested by the FAST (Fabric Assurance by Simple Testing) system. Findings indicate that the change in drape parameters (tension, stretch, and pressure) follows a definite pattern when the ease is varied within the pattern pieces keeping the fabric properties unchanged. This correlation between ease and virtual drape parameters leads to the development of a novel technique of virtual fit analysis by combining the objective technique (numerical analysis) with the prevailing subjective technique (visual

analysis). It is expected that this approach to fit analysis of virtual clothing will make the available virtual simulation tools more meaningful and useful to the designers, fit technicians and pattern cutters in the industry.

Keywords: Virtual Prototype, Drape Behaviour, Virtual Fit, 3D CAD, Tension Map

1. Introduction:

Although computer-aided design (CAD) systems for virtual fashion prototyping are available on the market since 2001 (Goldstein, 2009), they have found only a very limited application in the fashion industry so far. It claimed by the suppliers that such systems can ensure better communication of design throughout the supply chain and can offer a reduction in time and costs of product development (Ernst 2009). Within the available CAD systems, it is possible to rotate a virtual prototype in 360° for visual analysis of appearance and fit. At the same time a technical analysis using the tension, pressure, stretch and ease maps is also possible (Lim and Istook, 2011; Sayem, 2016). It is reported that the visual analysis is solely not enough for evaluating the virtual fit as the appearance of a virtual prototype can significantly differ from that of a real prototype (Kim, 2009; Lim, 2009 and Kim and LaBat, 2013). Often wrinkles are not accurately reproduced on virtual prototypes (Kim, 2009 and Kim and LaBat, 2013) and the visual appearance of simulated garments from identical material properties may differ in the system-to-system (Lim, 2009). Power et al. (2011) found that fabrics with vastly different properties appeared to have a very similar appearance in virtual simulations. This demands the use of an objective approach to the meaningful evaluation of virtual fit of clothing.

Wu et al. (2011) presented an objective approach to fit analysis of virtual clothing but their approach did not correspond to the fit analysis practice followed in the industry and neither utilised the fit evaluation tools offered in 3D CAD systems. Lim and Istook (2011) and Sabina et al. (2012, 2014 and 2015) utilised the colour coding of stretch and tension maps to evaluate fit in addition to drape image. However, they did not check the numerical value of tension working on the strained area to help decision-making. Porterfield (2015) applied the ease map to validate the fit of virtual costume but did not utilise any tension, pressure or stretch values. Power (2013) reported that virtual clothing prototypes with an insignificant visual difference could exhibit significant differences in pressure map. However, taking a decision based on visual analysis of colour codes or bands of tension, pressure and stretch maps is also a subjective approach and this can be quite misleading too. The colour bands of the tension maps from two different fabrics may look almost similar but maximum tension values may be far different from each other (Sayem, 2016). In order to quantify the virtual fit, it is first necessary to identify the correlation of the virtual drape parameters with the factors that cause a good or bad fit. After experimenting with men's virtual shirt, Sayem (2016) reported that the virtual drape parameters, such as tension (gf/cm), stretch (%) and pressure (dyne/cm2 or gm/cm2), exhibited good correlation with the change in ease and dimension of pattern pieces. This paper investigates the correlation between the change in ease in the bust area of pattern pieces and the change in virtual drape parameters of ladies blouse and it explores the concept of a "virtual fit prediction system" similar to the computerised 'colour matching system (CMS)' already in use in the industry. It is expected that the combination of this objective approach (i.e. numerical analysis of drape parameters) presented in paper with the prevailing subjective technique (visual analysis) will make the available virtual simulation tools more meaningful and useful to the designers, fit technicians and pattern cutters in the industry.

2. Methodology

The starting point of producing a virtual clothing prototype is to prepare an accurately sized and shaped avatar on which digital pattern pieces can be wrapped for drape simulation based on material properties. Accurate body measurements are necessary for drafting pattern pieces and for adjusting avatar dimensions within the 3D CAD environment. It was intended to prepare a set of pattern pieces of ladies' blouse in size "12" with varying eases around the bust girth. The BS 3666: 1992 (Specification for the Size designation of women's wear) provides a range of bust girth measurement from 86cm to 90cm for size '12' women. As suggested in Aldrich (2015), a bust girth of 88cm was selected as a control measurement for 12-sized women. Appropriate body measurements for pattern drafting and avatar dimensions were derived from body-scan data as described in the next sub-section. One commercial clothing CAD system with 2D and 3D modules was used for pattern drafting and implementing virtual simulation parts of this research. A poplin fabric of 35% cotton 65% Polyester was collected locally to test its mechanical properties by the FAST (Fabric Assurance by Simple Testing) system for use in virtual simulation.

2.1 Body Scanning & Measurement Extraction

In order to identify the representative body measurements of British women with an average bust girth of 88cm, a set of 66 female body-scans with the bust measurement ranging from 87cm to 89cm (with an average of 88cm) was identified from a data bank of body-scans, which has been developed in our institute by scanning interested female subjects using a KX-16 bodyscanner (TC[2], USA). Appropriate ethical measures were taken before and after the collection of body-scan data; each subject (aged over 18) voluntarily singed a consent form prior to body scanning and provided unrestricted clearance to capture, store and use of their scanned data for research purpose. The absolute anonymity of the participants has been ensured to maintain the confidentiality policy.

The KX-16 proprietary software system (version 2.2.1) was used to process the captured point-clouds as reduced body data (RBD) in ***.rbd** format and to inspect all the landmark locations prior to the measurement extraction from them. A measurement extraction protocol (MEP) was written to extract measurements from each of the body-scans within TC[2] system. The definitions of the major measurement parameters considered in the MEP (see Figure 1) are presented in Table 1. Finally, the body measurements from all female body scans were extracted into a Microsoft Excel sheet using the '*Batch Process*' tool of the KX-16 software. The average body measurements, as can be found in Table 2, were used for drafting pattern pieces and for preparing avatar for garment simulation.

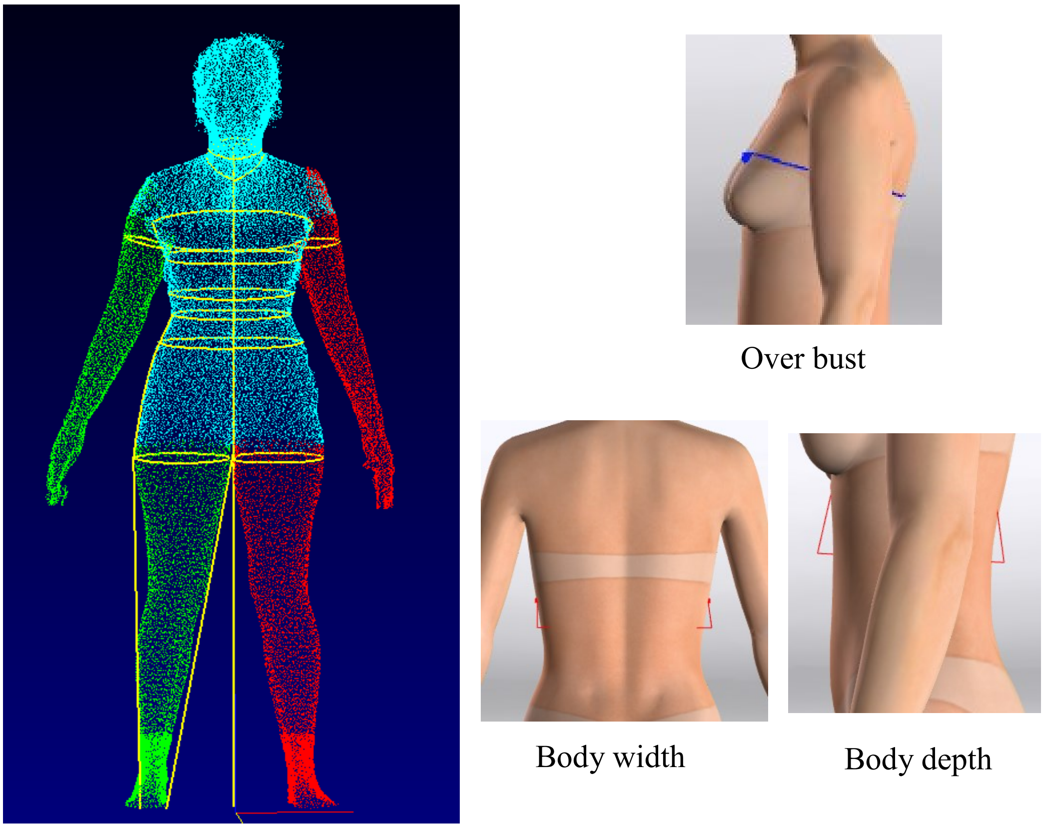


Figure 1: Major Measurement positions as defined in Table 1

Table 1: Definitions of major measurement parameters in TC^2 KX-16 MEP

Measurement Parameters	Definitions in KX-16 MEP
Cervical Height	Back neck height from floor
Neck Column girth	Measured at the middle of the neck where the collar of a dress shirt is usually positioned.
Neck base girth	Usual neck measurement at the neck base. It goes through the front neck point and the two side neck points
Overbust girth	Measured at an inclined plane above the bust at front and under the armpit (see Figure 1).
Bust girth	Measured at horizontal plane at the bust point level
Under Bust girth	In TC^2 system, it follows the 'under bust' definition measured using a horizontal plane.
Body width	Width at under bust position (see Figure 1)
Body depth	Different between the Front_X and Back_X at under bust position (see Figure 1). In TC^2 system, Front_X: is the distance of the front most point of the circumference from an imaginary plane 1 meter behind the crotch point. Back_X: is the distance of the rear most point of the circumference from an imaginary plane 1 meter behind the crotch point.
Waist	Smallest circumference around the torso within the 0 to 4 cm limits of centre back point height to locate 'small of back', which is roughly at the top of the pelvis.
High hip girth	Measured at a 75% distance between hip and back waist
Hip girth	The largest circumference between 90% distance from crotch to waist
Thigh girth	The largest circumference at a position between 2.54 cm below the crotch and knee.
Low thigh girth	Measured at 50% distance from knee to crotch
Arm Length	Measured from shoulder point to wrist
Upper biceps girth	2.5 cm above biceps
Bicep girth	The Biceps are found at 5.08 cm (i.e. 2 inches) below the armpit. It is not the largest circumference of the upper arm.
Outseam	Average of the distances above the floor of the left or right waist points.
Inseam	It follows the inside of the leg like a tape measure would do.

Table 2: Average Measurements from body-scans and effective Avatar measurements

SL	Measurement Parameters	Average measurements (cm)	Effective Avatar measurements (cm) in 3D CAD system
1	Height	165.27	165.27
2	Cervical Height	142.20	142.20
3	Neck Column girth	32.23	32.23
4	Neck base girth	35.26	35.26
5	Shoulder slope	5.54	5.54
6	Across shoulder	36.15	36.13
7	Overbust girth	85.75	85.75
8	Bust girth	88.12	88.12
9	Bust point to point	18.22	18.22
10	Bust point from High Point Shoulder (vertical distance)	21.02	21.02
11	Bust Height (from floor)	119.99	nn
12	Bust width	28.5	28.5
13	Across back	31.75	nn
14	Under bust girth	74.08	74.08
15	Under bust Height	113.57	113.57
16	Body Width	26.12	25.39
17	Body Depth	19.85	19.85
18	Waist girth	70.83	70.83
19	Waist to Hip	24.61	24.61
20	Back waist from Centre Back	40.47	42.47
21	Front Waist from Centre Front	34.33	36.33
22	High hip girth	80.86	80.86
23	High Hip Height	97.09	94.11
24	Hip girth	99.38	99.38
25	Hip Height	78.64	79.38
26	Thigh girth	55.72	55.72
27	Low thigh girth	46.77	46.77
28	Low thigh height	60.56	60.56
29	Knee girth	36.14	36.14
30	Knee height	45.38	45.38
31	Calf	35.09	35.09
32	Calf height	33.06	33.06
33	Ankle girth	24.15	24.15
34	Ankle height	7.59	11.74
35	Arm Length/overarm	54.86	54.86
36	Armscye girth (Armhole)	37.18	nn
37	Armscye Height	131.70	nn
38	Armscy depth	16.08	16.08
39	Upper biceps girth	28.06	28.06
40	Bicep girth	27.20	27.88
41	Elbow girth	22.58	22.08
42	Forearm girth	22.70	nn
43	Wrist girth	14.84	14.84
44	Outseam	104.33	102.27
45	Inseam	76.50	76.50
nn = not necessary			

2.2 Pattern Drafting

13 pairs of front and back panels with varying eases starting from 0.0 cm to 12 cm at the bust area at an interval of 1.0cm were drafted in the 2D window of the CAD system following the pattern cutting instructions for '*easy fitting bodice block (woven fabrics)*' presented in Aldrich (2015). Below measurements for front and back parts (see Figure 2) of women's blouse.

Bust girth: 88 cm with variable ease from 0.0 to 12.00 cm at every 1.0 cm interval;

Shoulder: 11.44 cm;

Nape to waist: 39 cm

Back width: 31.75 cm;

Waist to hip: 24.61cm;

Armscye depth: 16.08 cm;

Back neck to waist: 48 cm;

Neck Size: 35.26 cm;

Over bust width/chest: 34.52cm

Front Dart: 7cm

The pattern for sleeve was drafted pattern cutting instructions for 'one-piece sleeve block' presented in Aldrich (2015) using the below measurement.

Sleeve length: 48.5 cm.

Figure 2 shows the drafted outlines of the front, back and sleeve patterns. The front and back parts of the blouse were extracted from the outlines using tracing tools of the CAD system and finally mirrored to get the complete front and back parts. The drafting technique of Aldrich (2015) does not take the *upper bicep girth* and *bicep girth* into account for drafting the sleeve pattern. It has been found that the width of the sleeve pattern at the crown zone drafted following Aldrich (2015) was smaller than the upper bicep girth mentioned in Table 1. Therefore, the width of the sleeve was adjusted to 28.1 cm.

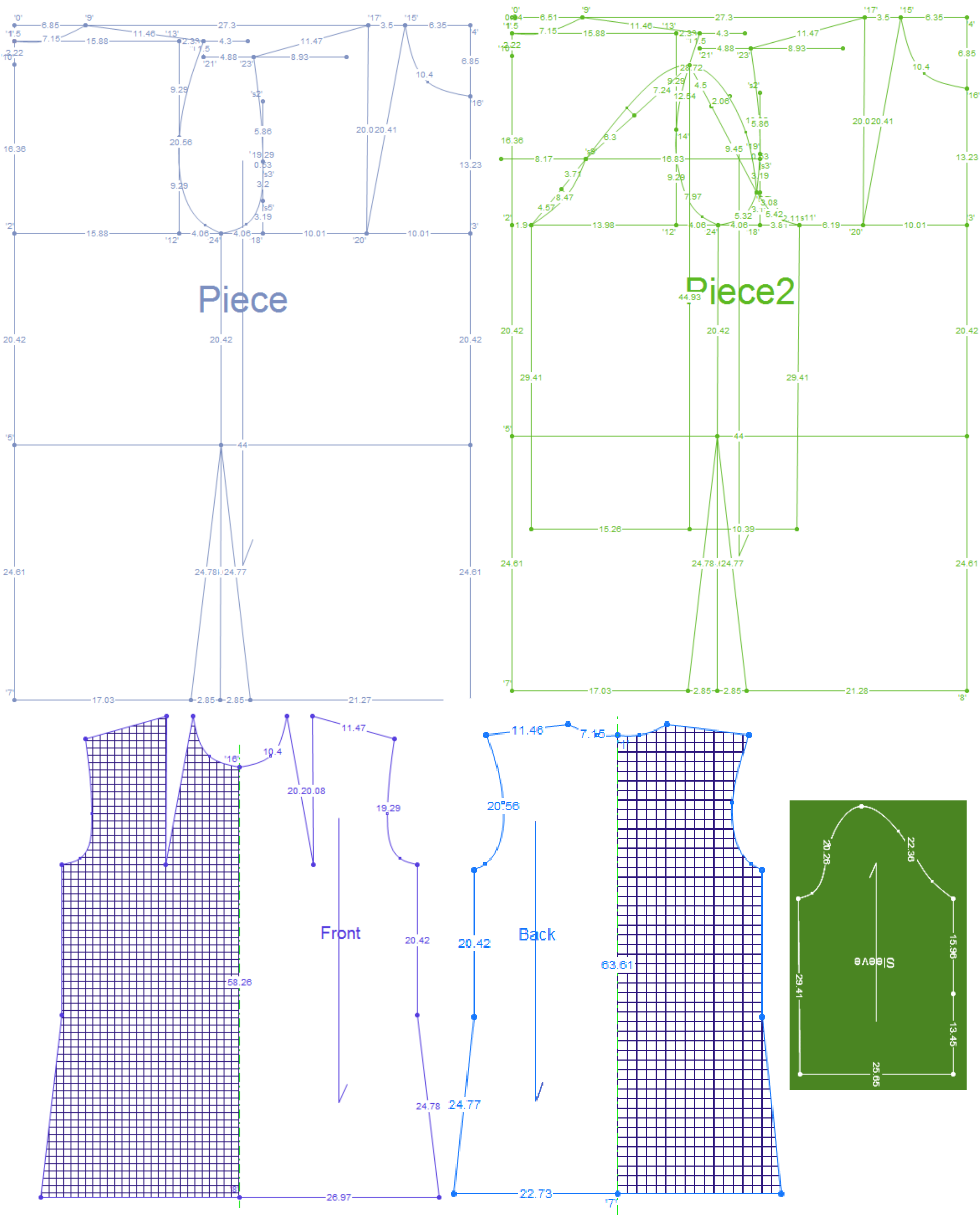
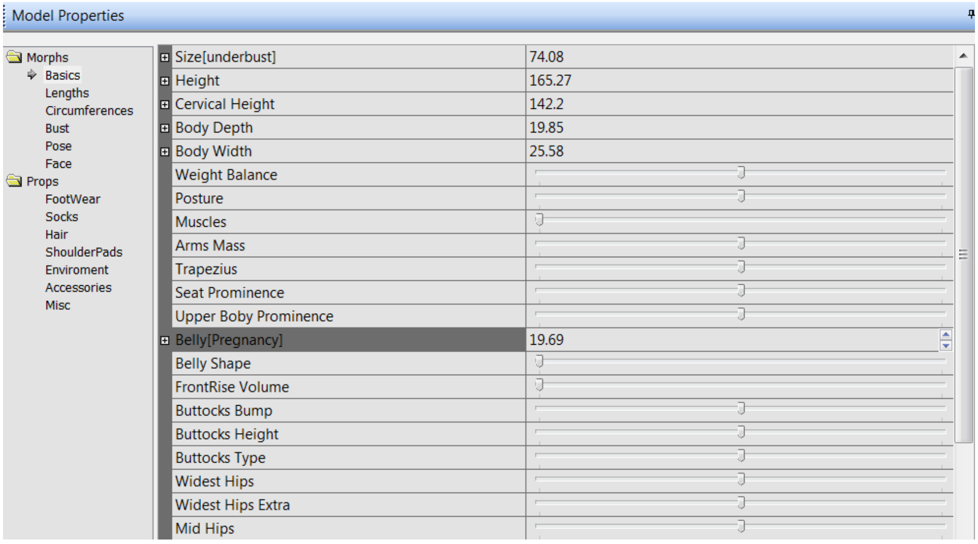


Figure 2: Drafted Outlines (top) and Extracted Pattern Pieces (bottom)

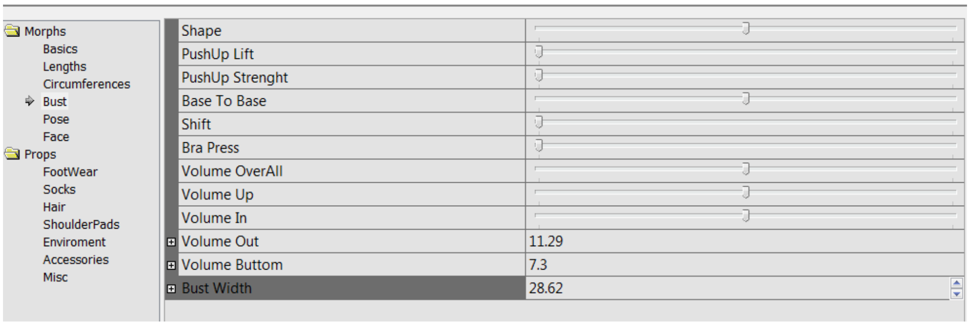
2.3 Avatar Morphing

An appropriate female model namely "PFA_EVA.mod" was selected from the mannequin library of the CAD system to manipulate its size and shape in order to reproduce the anthropometry of an average 12-sized British woman using the measurements given in Table 2. Under five functional morphing categories, namely ***basics, lengths, circumferences, bust*** and ***pose***, this CAD system uses in total 86 criteria to modify or adjust the anthropometric properties of a female figure. Out of these 86 criteria within the 'model properties window', 48 criteria accept numerical inputs of measurements. Remaining 38 criteria offer only sliding bars (see Figure 3) to adjust measurements instead of any option for inputting numerical values directly. Out of 48 criteria that accept numerical inputs, 45 could be adjusted using the measurements extracted from body-scan data as presented in Table 02. For 3 criteria namely belly (pregnancy), bust volume out and bottom there are no measurements available from body-scan data as these are not commonly used parameters for apparel construction and there are also no definition for them is available in BS EN 13402-1:2001 (Size designation of clothes- Part 1; Terms, definitions, and body measurements procedure). Therefore these three criteria can also be adjusted by sliding bar movement (see figure 3).

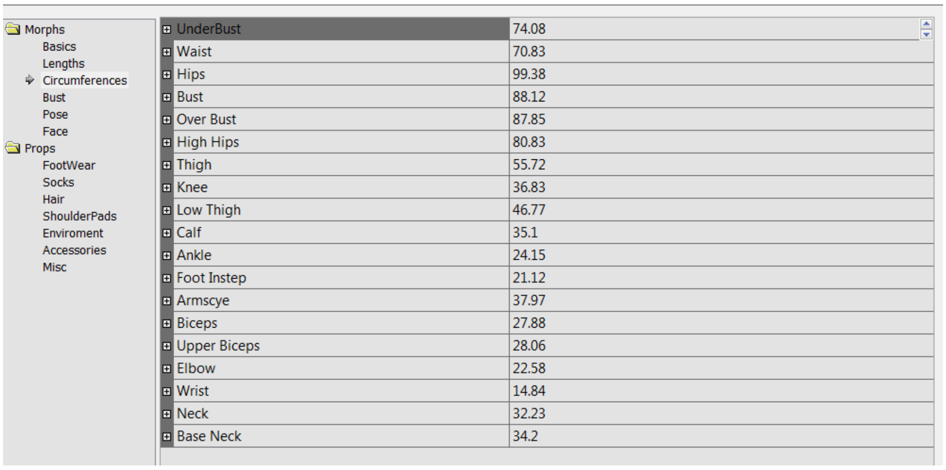
It has been experienced while morphing the body size and shape of the female mannequin of CAD system using the average body measurements (Table 1) of British 12-sized female figures that the software system does not provide absolute freedom to modify all of the morphing criteria. As some of the criteria are inter-related as programmed by the supplier, the values of body width, back and from the waist, hip and high hip height, ankle height, bicep girth and outseam were not fully accepted by the system, as presented in table 1.



a) Basics



b) Bust



c) Circumferences

Figure 3. Avatar Morphing Windows of 3D CAD system

2.4 Fabric Parameters for Simulation

The physical and mechanical properties of fabric which are required for realistic drape simulation are weight, thickness, resistance to bending, resistance to stretch, resistance to shear, the coefficient of friction etc. (Luibe and Magnenat-Thalman, 2007 and 2008). Ideally, these need to be measured in a low force environment that corresponds to the loads a fabric is likely to undergo during garments manufacturing and wear (Sayem, 2016). The KES-f (Kawabata Evaluation System for fabrics) and FAST are two commonly used objective evaluation techniques that measure mechanical properties of fabrics under low force unlike the traditional physical and mechanical test methods described in ISO (International Organization for Standardization) and ASTM standards. It is reported that few companies, for example, Browzwear and OptiTex, have recently introduced their own fabric testing kits to get parameters for drape simulation and took away the KES-f and FAST data converters from the latest releases of their software packages. However, these newly commercialised fabric testing systems need standardisation (Power, 2013), approval, and accreditation from the international standardisation bodies to be able to be used with confidence in the industry. The KES-f parameters were used by Breen et al. (1994) and Eberhardt et al. (1996) to simulate virtual clothing. The FAST system was used by Kim (2009), Lim (2009), Lim and Istook (2011), Wu et al. (2011) and Kim and LaBat (2012) for simulation of garments on a virtual mannequin.

2.4.1 FAST Testing

In this research, a shirting fabric as mentioned in Table 03 was tested by a FAST system for deriving the required parameters for use in virtual simulation. The fabric was conditioned as per BS 139 - 2005 and all the tests were carried out in the standard atmosphere (20°C temperature and 65% RH).

The FAST system, also known as SiroFAST, consists of the following three instruments and a test method:

- SiroFAST-1 (a compression meter that measures fabric thickness);
- SiroFAST-2 (a bending meter that measures the fabric bending length);
- SiroFAST-3 (an extension meter that measures fabric extensibility); and
- SiroFAST-4 (a test procedure for measuring dimensional properties of fabric).

The SiroFAST-1 'compression meter' defines surface thickness (ST) as the difference in the fabric thicknesses T2 and T100 measured at two different loads: 2 gf/cm^2 (19.6 mN/cm^2) and 100 gf/cm^2 (981 mN/cm^2) respectively, i.e., ST = T100-T2.

The SiroFAST-2 'bending meter' measures fabric bending lengths in warp and weft directions using the cantilever bending principle, as described in British Standard Method BS:3356 -1961. From the values of bending length obtained, the bending rigidity of the fabric is calculated using the eq. 1.

Bending Rigidity, B (μN.m) = $9.81 \times 10^{-6} \times WC^3$ ………………(1)

Where C is the bending length measured in mm and W is the fabric weight in g/m^2.

The SiroFAST-3 'extensibility meter' measures the extensibility of a fabric under three different loads namely 5, 20 and 100 gf/cm (i.e 4.9, 19.6 and 98.1 N/m). The loads are chosen to simulate the level of deformation the fabric is likely to undergo during garment manufacture. SiroFAST-3 also measures the bias extensibility of the fabric (at 45° to the warp direction) under a low load (5 gf/cm). Bias extensibility is used to calculate shear rigidity using the eq. 2.

Shear Rigidity, G (N/m) = 123/EB5 …………………… (2)

Where EB5 is the bias extensibility in %.

Table 3: Fabric Parameters for Virtual Simulation

Fabric Type: Shirting; **Composition:** 35% Cotton 65%Polyester			
Construction: Ends: 45/cm; Picks:31/cm; 1/1 Plain weave			
FAST Data		**Converted Data for CAD System**	
Parameters (Unit)	**Value**	**Parameters (Unit)**	**Value**
Extensibility (%) at Warp [E100-1]	1.07	Resistance to Stretch (g/cm) at warp	3605.76
Extensibility (%) at Weft [E100-2]	1.8	Resistance to Stretch (g/cm) at weft	2136.75
Bending Rigidity (μN.m) at Warp	9.07	Resistance to Bend (no unit) at warp	906.89
Bending Rigidity (μN.m) at Weft	4.02	Resistance to Bend (no unit) at weft	401.72
Shear Rigidity (N/m)	103.94	Resistance to Shear (no unit)	1039.44
Thickness (mm)	0.148	Thickness (cm)	0.0148
Weight (gsm)	110	Weight (gsm)	110

2.4.2 Parameter Conversion for Virtual Simulation

The fabric parameters required by the selected CAD for virtual simulation of garments are weight (gsm), thickness (cm), resistance to stretch (gr/cm), resistance to bend (no unit) and resistance to shear (no unit). Definitions of last three parameters specific to the CAD system in use and their relationship with the FAST parameters are presented in Table 4. Expect weight (g/m^2), other parameters from the FAST test cannot be input directly to the 3D simulator.

Table 4: Parameters Definitions and relationship with FAST results

#	Fabric Parameters	Definitions used by the CAD system in use	Relationship with FAST parameters
1	Resistance to stretch	The resistance of the cloth to stretching forces in the warp and weft directions and it affects the elasticity of the fabric	can be derived from the Extensibility (%) [E100-1 & E100-2].
2	Resistance to bend	The resistance of the cloth to Bending forces that affects the rigidity of the fabric	can be derived from Bending Rigidity (μN.m)
3	Resistance to shear	The resistance of the fabric to shearing forces in the diagonal direction of the fabric and it affects the stiffness of a fabric when cut in bias direction.	can be derived from FAST parameter Shear Rigidity (N/m)

The fabric converter (shown in Figure 4) available in PDS 10 was used similarly to the work of Lim and Istook (2011) to convert all FAST parameters into the compatible parameters of the CAD system, as presented in Table 3. It should be noted that the conversion of resistance of *Bend* and *Shear* achieved from the fabric converter of CAD system does not correspond to the known mathematical relationships of the relevant units, therefore those are mentioned as ‘no unit’ in Table 3. As the FAST system does not measure the coefficient of friction, a value of 0.15 is used following the findings of Ghani (2011), who reported that the coefficient of friction of medium weight fabrics weighing between 101 and 135 gsm) of polyester-cotton varied from 0.14 to 0.20.

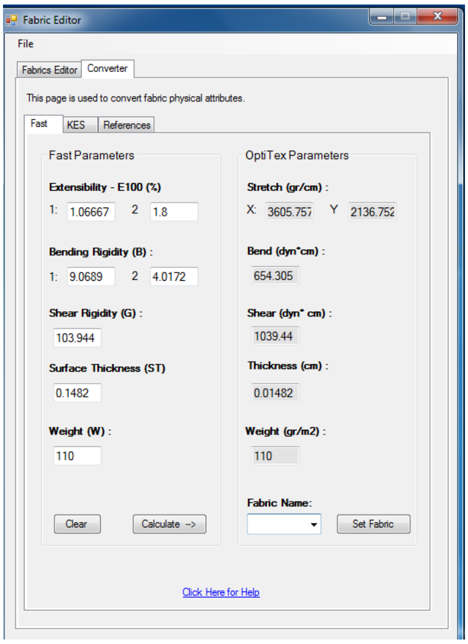


Figure 4. Fabric Converter of CAD System

2.5 Blouse Simulation

All front and back pattern pieces (13 pairs with varying eases starting from 0.0 cm to 12 cm at the bust area at an interval of 1.0cm as described in section 2.2) were simulated on the avatar described in section 2.3 within the 3D window of the CAD system. For each case, the simulation was done twice, with and without the sleeves. The process included: defining stitches and seam lines on the 2D pattern pieces (see Figure 5), defining the position and 3D shape of each pattern on Avatar, assigning fabric properties, placing pattern pieces on the avatar and finally running the drape simulation engine (see Figures 5 &6). During the simulation, the relevant properties such as gravity, world damping, bending, and time step, iteration per frame, stitch constant and stitch damping were maintained as a default setting, as presented in Figure 7.

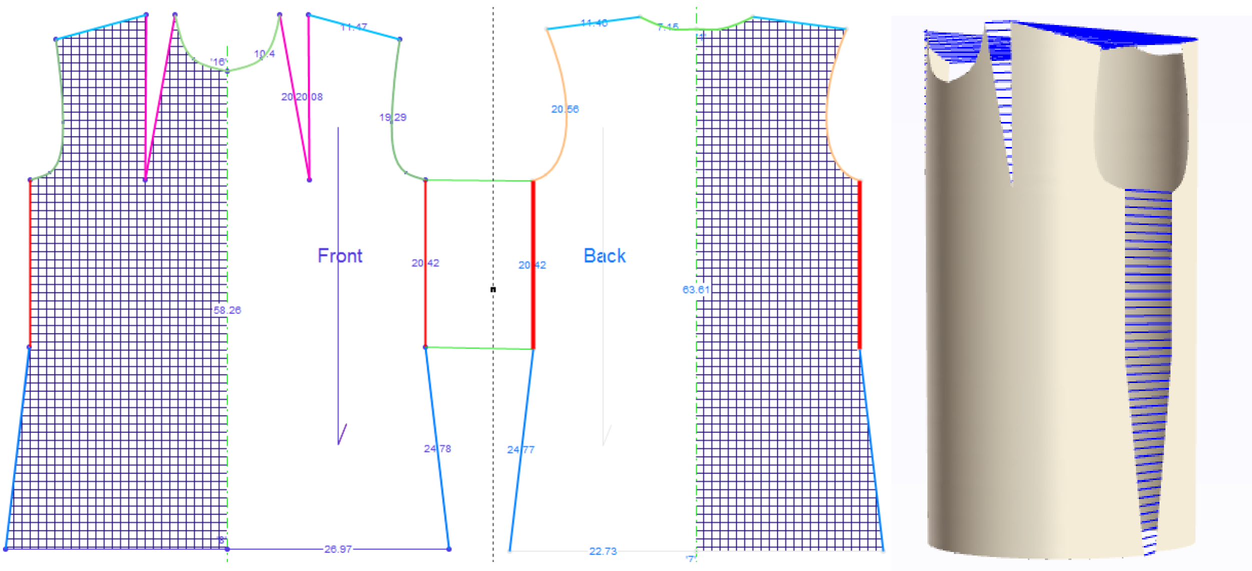


Figure 5. Definitions of Stitches and Seamlines (2D & 3D Views)

Figure 6. Pattern Placement on Avatar (left) and Virtual Blouse after Simulation

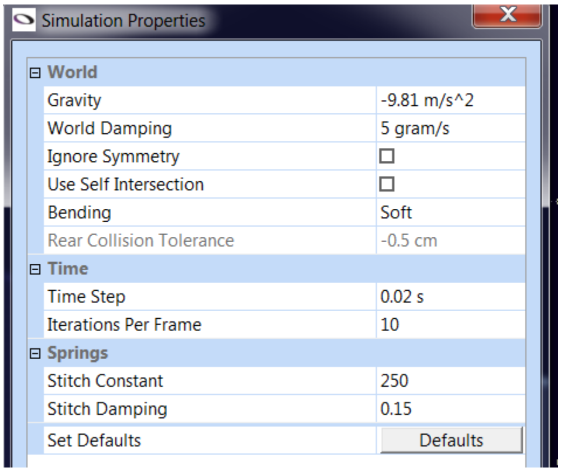


Fig. 7 Simulation Properties used in 3D CAD System

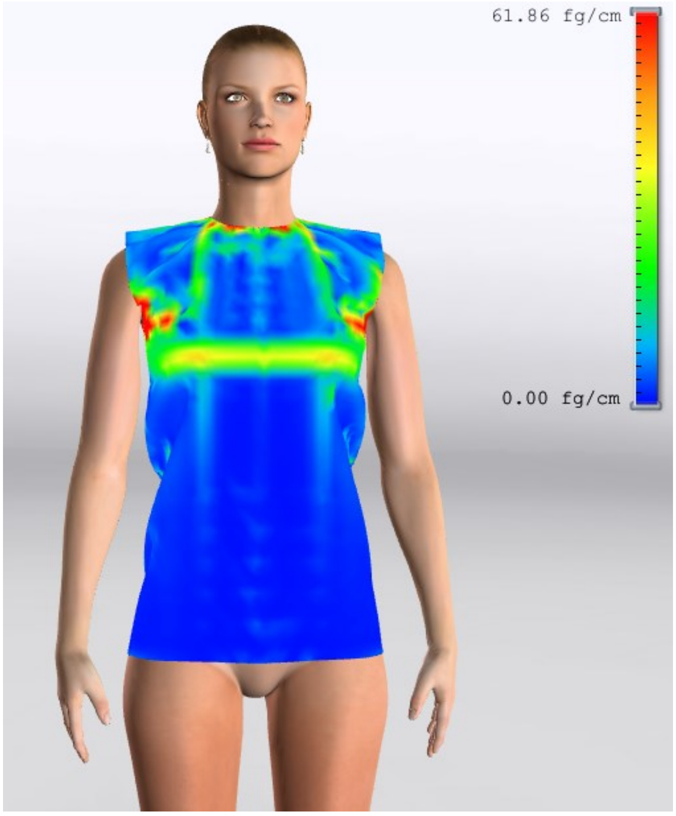
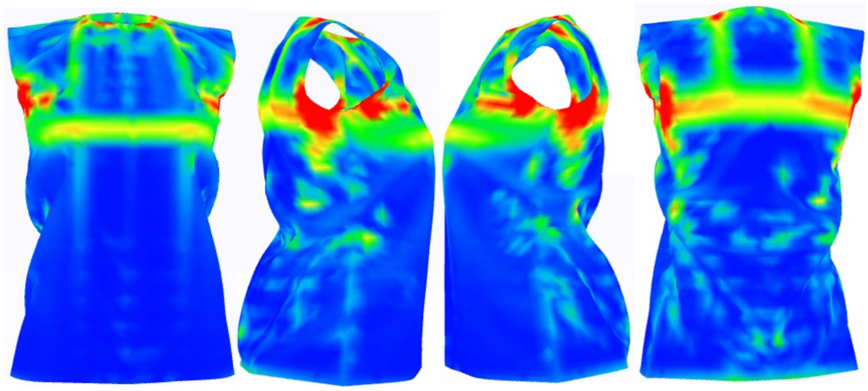


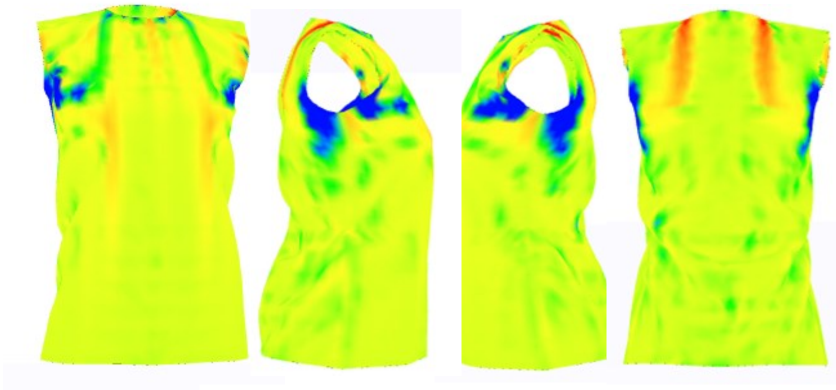
Figure 8. Tension map of Sleeve-less blouse with no Ease at the Bust area

2.6 Analysis of Drape Parameters

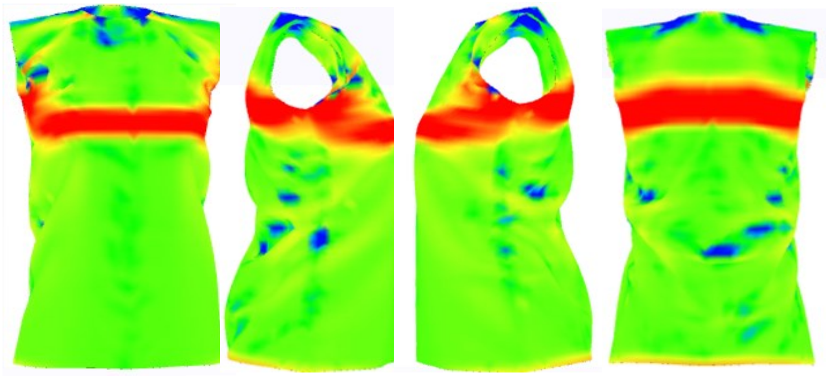
Three virtual drape parameters namely tension (gf/cm), stretch (%) and collision pressure (dyne/cm^2) were analysed to evaluate the fit of virtual blouses simulated from each and every pairs of patterns mentioned in section 2.2. The amount of virtual tension (i.e. the forces working in unit length) influencing the cloth was analysed in three ways, namely total tension [see Figure 8] and tensions in the warp and weft directions. The colour band on the tension scale ranges from blue through green and yellow to red where blue stands for minimum and red stands for maximum values of virtual tension. Similarly, the amount of fabric expansion is analysed in three ways, namely total stretch and stretches along the warp and weft directions were analysed. The stretch scale is also similar to tension scale in terms of colour coding. Additionally, the normal collision pressure (dyne/cm^2) at the contact point of virtual fabric and skin of the virtual mannequin was also analysed. The simulation tool was run for three times for every pair of pattern pieces to get a stable simulation before recording the values of tension, stretch, and collision pressure. The maximum values were then identified by hovering the mouse pointer on the bust area covering both left and right sides of the body up to the armhole.



Map of Total Tension



Map of Tension in Warp direction



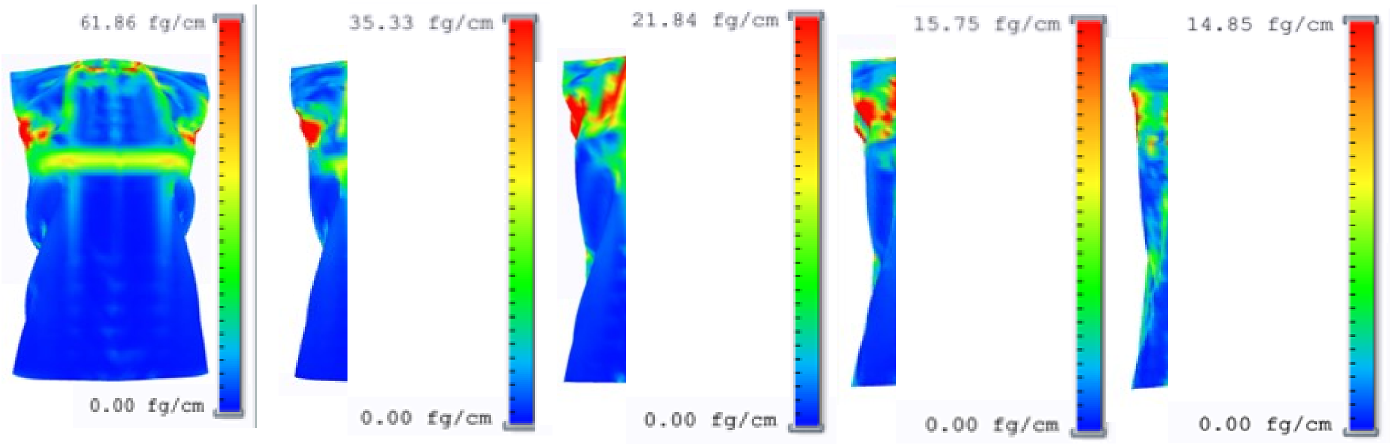
Map of Tension in Weft Direction

Figure 9. Different views of Tension maps on Sleeve-less blouse with no Ease

3. Results & Discussion

3.1 Virtual Blouse without Sleeves

Table 5 shows the maximum values of tension, stretch and collision pressure for 13 pairs of front and back panels with varying ease starting from 0.0 cm to 12 cm at the bust area at an interval of 1 cm for the sleeveless blouse. With no ease at the bust area, the blouse is constrained at the bust area and for the properties of the 35/65 Cotton-Polyester blended fabric considered in this study, the maximum tension found on the blouse was 61.86 gf/cm (see Table 4 and Figures 10 and 11). The maximum tension was found to be concentrated at the sides of the bust area underneath the armholes, as it can be seen in figure 9, and the tension in fabric acts mainly in the weft direction. As the pattern pieces started to include ease at the bust area, the maximum tension also started to fall down. Up to 2cm ease, a drastic reduction of tension was seen for an increase of every cm of ease. When the ease was between 2 cm and 7 cm, a gradual decrease in tension over the virtual fabric took place as can be seen in Figure 10 and 11 and in Table 5. However, when the ease was between 8 cm and 12cm, the maximum tension in virtual fabric did not vary significantly, as it can be seen in Figure 10 and Table 4.



a) Zero Ease **b) 3 cm Ease** **c) 6 cm Ease** **d) 9 cm Ease** **e) 12 cm Ease**

Figure 10. Tension Maps on the Virtual Sleeveless Blouse with varying ease at Bust area

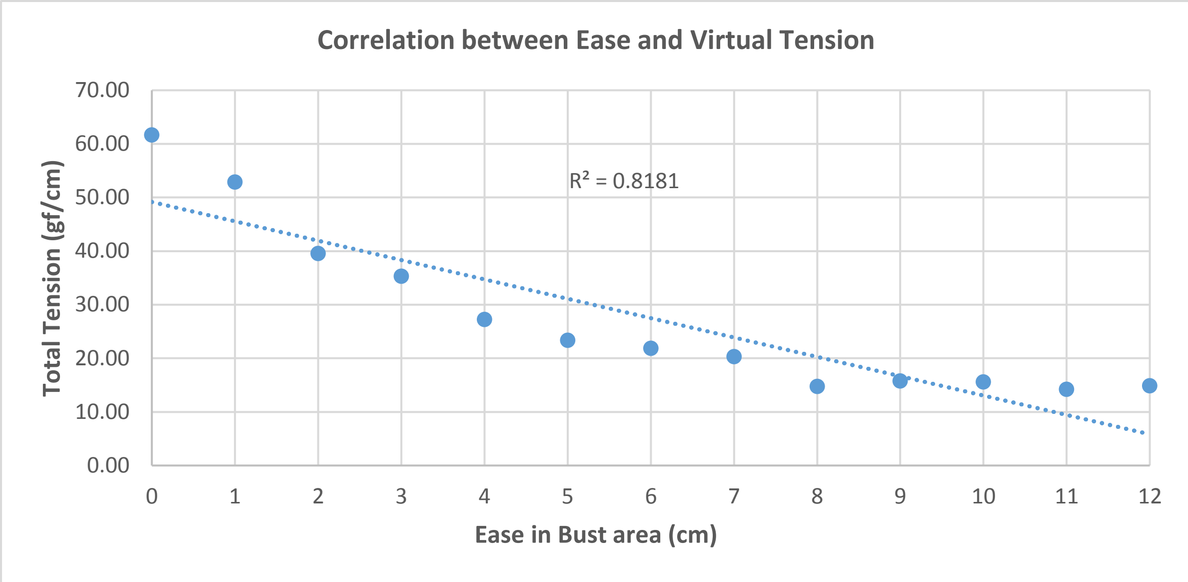
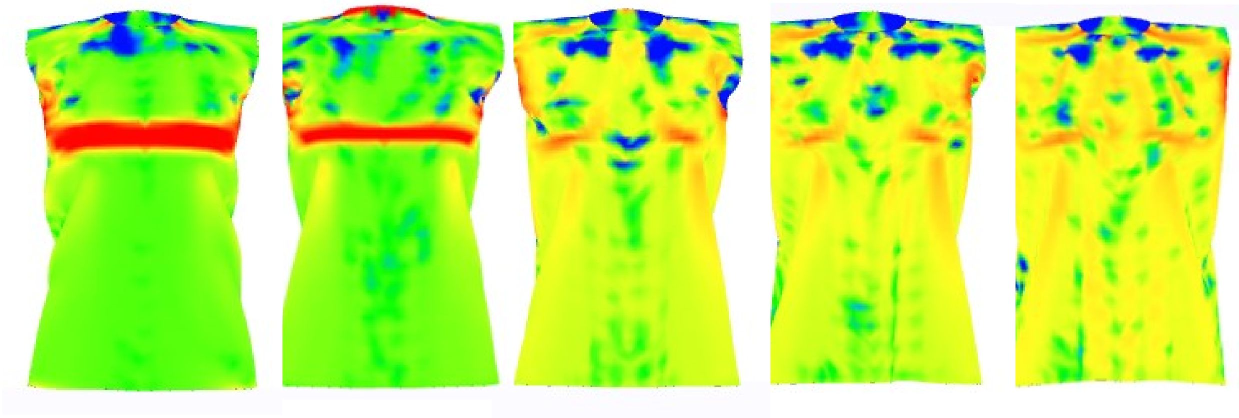


Figure 11. Correlation between Ease in Pattern and Tension in Virtual Fabric of the Sleeveless Blouse

In stark to virtual tension, the stretch in virtual fabric was found to be working in the middle of the bust zone and maximum stretch was found as 2.68% when there was no ease in the bust area of the virtual blouse. As the ease began to increase, the value of maximum stretch began to decrease and started to spread towards the upper chest area (see Figure 12). It is evident from the Figure 12 that stretch in the virtual fabric is mostly active in the weft direction. Similar to the phenomenon of tension distribution described earlier, the maximum stretch in virtual fabric also experienced a drastic reduction with the increase of ease up to 3 cm as it is evident in Figure 13 and Table 4. When the ease was increased gradually from 3 cm to 8 cm, a gradual decrease in the stretch in the virtual fabric took place as it can be seen in Figure 13 and in Table 5. However, when the ease at chest was between 9 cm and 12 cm, the maximum stretch in virtual fabric did not vary significantly, which can be seen in the Figures 12, 13 and Table 5.



a) Zero Ease b) 3 cm Ease c) 6 cm Ease d) 9 cm Ease e) 12 cm Ease

Figure 12. Stretch Maps on the Virtual Sleeveless Blouse with varying ease at Bust area

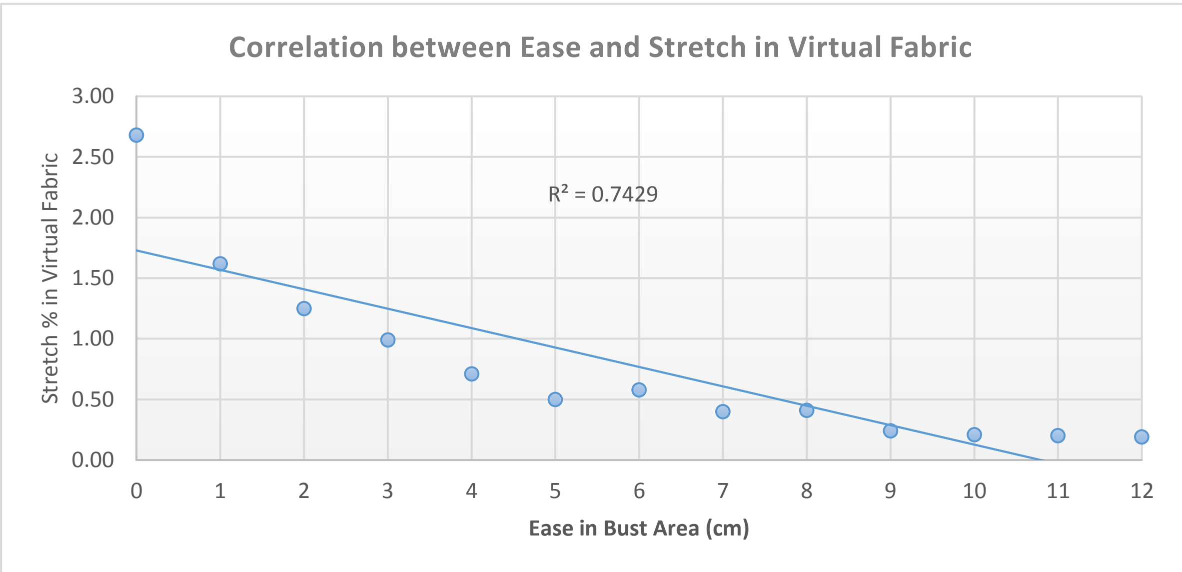


Figure 13. Correlation between Ease in Pattern and Stretch in Virtual Fabric of Sleeveless Blouse

The analysis of the collision pressure (dyne/cm^2) at the contact point of virtual fabric and skin of the virtual mannequin indicates that the correlation between ease and pressure is not very significant (see Figure 14).

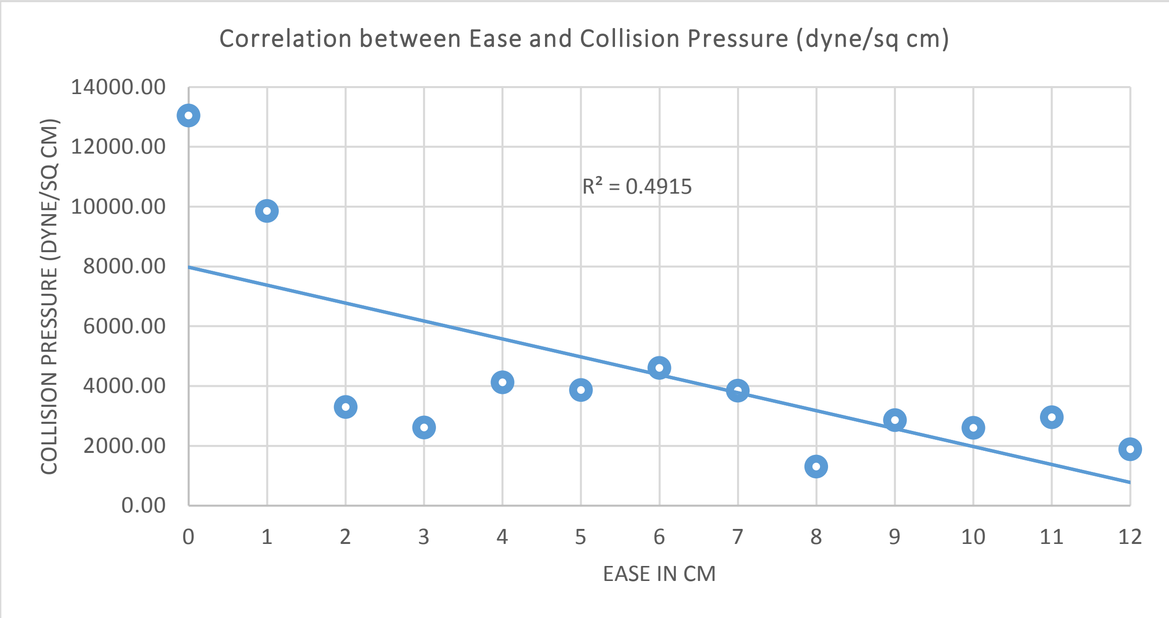


Figure 14. Correlation between Ease in Pattern and Pressure in Virtual Fabric of Sleeveless Blouse

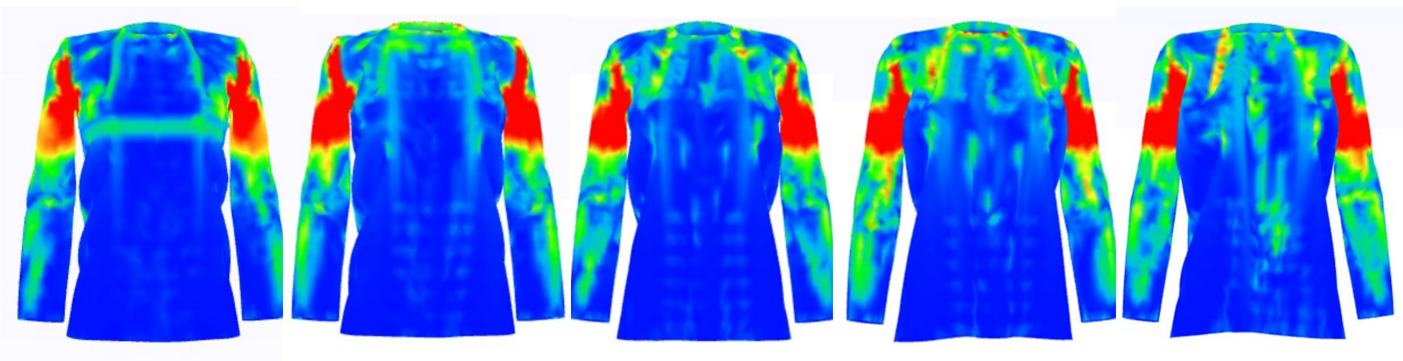
Table 5: Virtual Drape Parameters with varying Eases at the bust zone in Simulated Sleeveless Blouse.

Ease at bust area	Total Tension (gf/cm)	Total Stretch %	Normal Collision Pressure (dyne/sq. cm)
0	61.86	2.68	13051.80
1	52.90	1.62	9852.91
2	39.57	1.25	3303.29
3	35.33	0.99	2611.66
4	27.27	0.71	4125.87
5	23.35	0.50	3868.93
6	21.84	0.58	4603.03
7	20.30	0.40	3850.30
8	14.74	0.41	1309.26
9	15.75	0.24	2859.35
10	15.57	0.21	2598.27
11	14.22	0.20	2960.28
12	14.85	0.19	1888.80

It is clear from the above-mentioned findings that any change in the bust ease from zero to 2cm in women’s blouse influenced the mechanical behaviour of virtual drape significantly and any change in ease between 8 cm and 12 cm does not affect the mechanical behaviour of virtual drape in any notable way. The correlations between change in ease and drape parameters (p values 0.0000217 and 0.00015 for tension and stretch respectively) are statistically significant.

3.2 Virtual Blouse with Sleeves

For the full-sleeve virtual blouse, the tension and stretch followed a similar pattern seen in the case of the sleeveless blouse. Table 6 shows the maximum values of the virtual drape parameters of the full-sleeve virtual blouse made of pattern pieces with varying eases at the bust area. When there was no ease at the bust area, the maximum tension working in the virtual fabric at the bust girth zone was found as 113.72 gf/cm, which is found to be active at the sides of the body and biceps area of the sleeves. Figure 17 indicates that the maximum tension at the bust zone begins to decreases with the increase of ease in the pattern pieces. A rapid decline of tension up to a 2cm increase in ease, a gradual decrease between 3cm and 7cm of eases and no significant change when ease is increased beyond 8cm was observed. The nearly similar trend can be seen in Figure 18 that shows the correlation between ease in pattern and stretch (%) of virtual fabric. As it can be seen in figure 16 that maximum fabric stretch took place mainly at the back and biceps area. Similar to the sleeveless blouse, collision pressure in full-sleeve blouse follows a decreasing trend with an increase in ease but the correlation is not very predictable. The correlations between change in ease and drape parameters (p values 0.0000017 and 0.000018 for tension and stretch respectively) are statistically significant.



a) Zero Ease b) 3 cm Ease c) 6 cm Ease d) 9 cm Ease e) 12 cm Ease

Figure 15. Tension Maps on the Virtual Full-sleeve Blouse with varying ease at Bust area

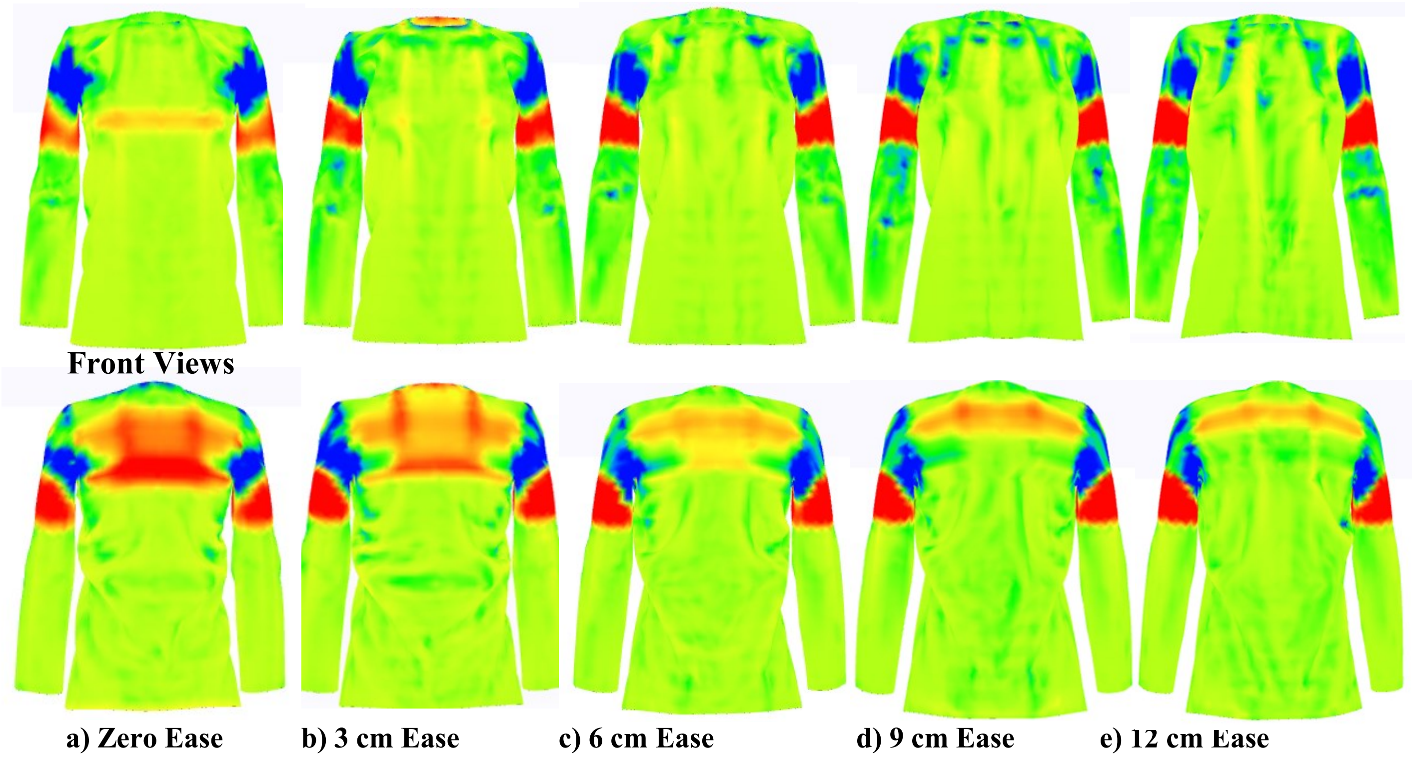


Figure 16. Stretch Maps on the Virtual Fullsleeve Blouse with varying ease at Bust area

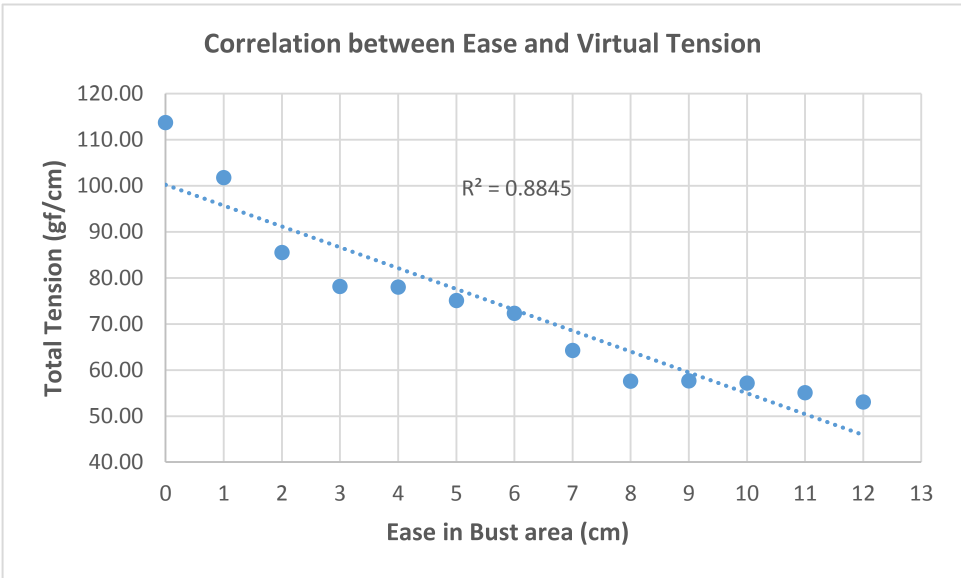


Figure 17. Correlation between Ease in Pattern and Tension in Virtual Fabric of the Full-Sleeve Blouse

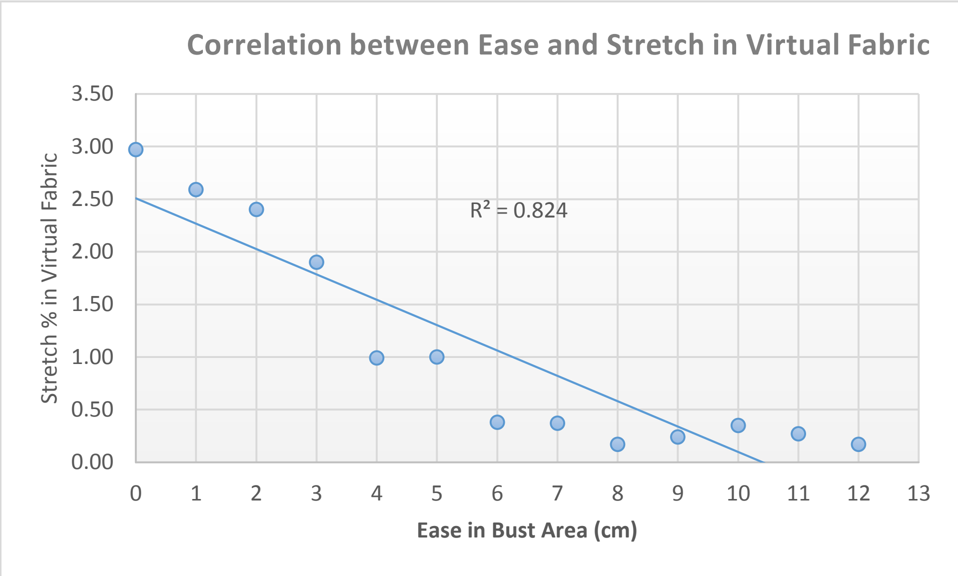


Figure 18. Correlation between Ease in Pattern and Stretch in Virtual Fabric of the Full-Sleeve Blouse

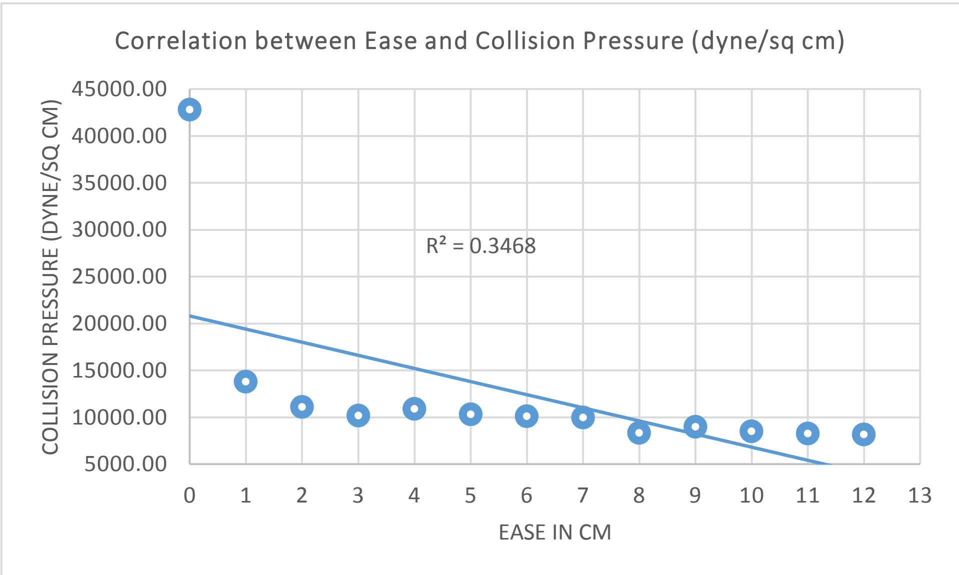


Figure 19. Correlation between Ease in Pattern and Collision Pressure in Virtual Fabric of the Full-Sleeve Blouse

Table 6: Virtual Drape Parameters with varying Eases at the bust zone in Simulated Full-Sleeve Blouse.

Ease	Total Tension (gf/cm)	Total Stretch %	Normal Collision Pressure (dyne/sq. cm)
0	113.72	2.97	42810.36
1	101.82	2.59	13789.68
2	85.54	2.40	11111.82
3	78.17	1.90	10170.11
4	78.07	0.99	10906.49
5	75.13	1.00	10304.08
6	72.37	0.38	10100.48
7	64.29	0.37	9986.43
8	57.63	0.17	8342.89
9	57.67	0.24	8992.23
10	57.18	0.35	8502.05
11	55.11	0.27	8279.28
12	53.12	0.17	8160.29

3.3 Discussion

Results presented in section 3.1 and 3.2 indicate that two virtual drape parameters (tension and stretch) are significantly correlated with the change in ease in pattern pieces. The values of these parameters can be used to predict the required level of ease to achieve a required level of fit of the garment. Sayem (2016) reported similar findings after experimenting with virtual men's shirts. Ease is an important factor of clothing fit and this can be either functional or design related. The correlation between ease in pattern pieces and virtual drape parameters can be utilised to predict the required level ease to achieve a good fit. If the fabric-specific values of virtual drape parameters of pattern pieces representing an accepted "good fit" for a certain style can be stored in a database, it will then help to predict the fit quality of any newly designed pattern sets of a similar style. This leads to the concept of a 'virtual fit prediction system' similar to the 'colour matching system (CMS)' used in the textile colouration industry (see figure 20). A CMS can predict the dyeing recipe for an unknown colour or can decide the "pass/fail" result of a dyed sample comparing with a standard. To be able to predict the recipe of any given colour, the system should have a built-in library of colour values (the spectral values following a colour theory, for example, CIE Lab theory, read by a spectrophotometer) and the corresponding dyeing recipes (list and quantity of dyestuff and associated chemicals). Employing the computational logic, a CMS can suggest the appropriate recipe for an unknown colour by matching its spectral values with the stored information in its database. It also can make a decision on a newly produced sample by comparing spectral values with the values of a colour standard pre-stored in its database. Similarly, by having a pre-built database of fabric-specific virtual drape parameters of differently designed pattern pieces will guide to proper selection and prediction of required ease and judgment of the fit quality of virtual clothing. It is expected that such an objective approach to fit analysis together with the traditional visual analysis will help fit technicians to take a decision on the 'acceptance or rejection' of any newly developed pattern sets without seeing the physical prototype, and this may lead to manufacturing garment with zero physical prototyping.

Figure 20. Spectrophotometric Colour-Matching System used in Textile Industry

4. Conclusion

There has been no standard protocol or guideline of virtual fit evaluation available; therefore, the tools for virtual fashion prototyping are yet to find any notable application within the industry, especially at the manufacturer's end. Several researchers (Kim, 2009; Lim, 2009 and Kim and LaBat, 2013) reported that only visual analysis did not provide enough clues for effective decision-making on the acceptance or rejection of a virtual prototype, or on altering pattern pieces to achieve expected fit in the virtual and ultimately in the physical garments. This research presented an objective approach to analyse the virtual drape of ladies blouses using virtual drape parameters. Findings show that the virtual drape behaviour of fabric can be numerically measured and the values of virtual tension and stretch correlate with the change of ease in the 2D pattern pieces. This will help the designers and technicians to predict the required level of change in ease and design in the 2D pattern pieces to achieve the desired drape and fit of the virtual garment. This also leads to the concept of an intelligent "virtual fit prediction system" principally similar to the colour matching system currently in use in the textile industry.

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